SIGNIFICANT GOLD DEPOSITS

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ABSTRACT

According to the available records, only 400,000 ounces of gold, 160,000 ounces of silver, 900 ounces of platinum, 17,000 ounces of palladium, 29,000 pounds of lead, nearly 64 million pounds of copper and 135 million tons of iron were produced in Wyoming in the past (Hausel, 1998a). Even so, the geology is favorable for discovery of significant precious metal deposits and with continued exploration by mining companies, precious metal production in Wyoming should dramatically eclipse past production.

INTRODUCTION

Minor to significant gold is scattered throughout the stratigraphic record of Wyoming, with the greatest concentrations in Precambrian and Tertiary rocks (Figure 1). Much of Wyoming is underlain by cratonic rocks (Archean). This complex includes several significant precious metal deposits; the most notable are structurally complex gold deposits associated with shear zones within folded greenstone belts. Gold found in such belts may have the highest potential for significant gold discoveries in Wyoming, although the complexity of the structural control on mineralization has befuddled most prospectors and geologists.

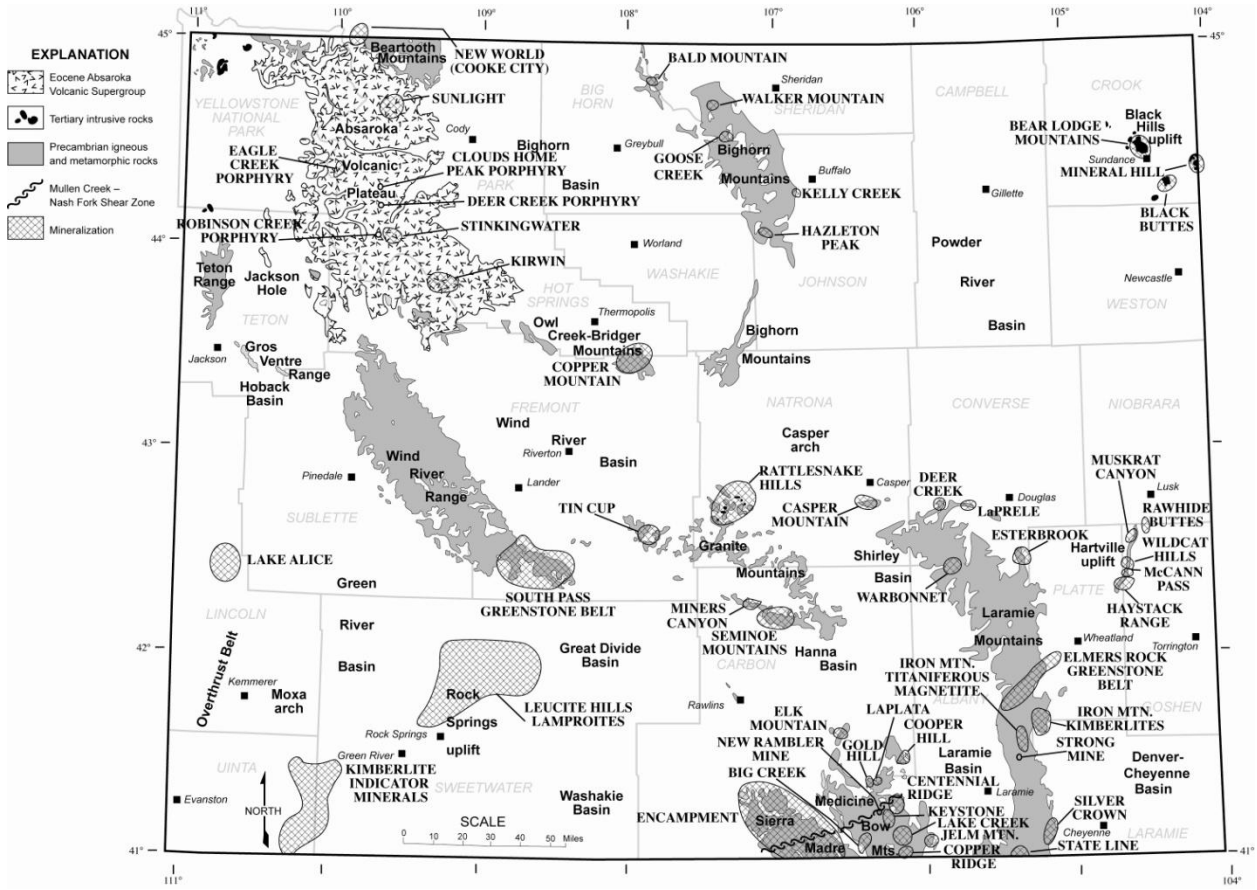


Figure 1. Mining districts and mineralized terrains in Wyoming.

In southeastern Wyoming, thick successions of Proterozoic metasedimentary rocks crop out in miogeosynclinal wedges that unconformably overlie the Archean basement. These include quartzite-hosted Cu-Ag-Au deposits, Au-Ag veins, and radioactive Witwatersrand-type metaconglomerates with isolated gold and diamond anomalies. The miogeoclinal terrain is separated from a metavolcanic terrain to the south by a Precambrian suture zone (Houston and others, 1968). This suture, or shear zone, hosts a few scattered Cu-Au-Ag and Pt- Pd-bearing deposits in cataclastics.

South of the suture, Proterozoic rocks (1.8 to 1.6 Ga) include volcanogenic Zn-Cu-Ag massive sulfide deposits, at least one Au-Cu porphyry (Copper King), two large layered mafic complexes (1.8 Ga) and a pyroxenite massif with anomalous Pd-Ni-Au-Pt-Ag-Cu at Puzzler Hill. Along the northern edge of one layered mafic complex (Mullen Creek) Pd-Pt-Cu-Au-Ag was recovered from the New Rambler mine at the start of the 20th century. One estimate suggests that 900 ounces of Pt and 17,000 ounces of Pd were recovered along with the copper and gold.

A 350 mi^2 anorthosite batholith (1.4-1.5 Ga) in the Laramie Mountains has long been considered a possible source of low-grade aluminum as well as extensive disseminated and massive Ti-Fe-V deposits. In addition, one isolated deposit near the southern margin of the batholith is interpreted as a Cu-Au-Ag-W-Mo vein deposit. Even more impressive is the potential for world-class iolite gem deposit with possibilities for more than a trillion carats in gemstones recently recognized by the author. Another world-class iolite gemstone deposit was identified to the west of the anorthosite complex within the Archean basement terrain that hosts some of the largest colored gemstones on earth (Hausel, 2005).

Phanerozoic rocks have few precious metal occurrences. Where found, these include Au-REE anomalies in Cambrian conglomerates and Ag-Cu-Zn stratabound mineralization in Jurassic redbeds. Rocks of Late Cretaceous age along the flanks of some uplifts have scattered black titaniferous sandstones. Detrital heavy minerals with anomalous Ti, Zr, REE, and in some cases Au, are found in some of these.

However, Tertiary rocks host significant anomalies. Some of the largest ore deposits and areas of mineralization in the state include Cu-Ag porphyries in the Absaroka Mountains. This deeply incised volcanic plateau includes several composite stocks with zoned hydrothermal alteration and mineralization with significant Cu, Ag, Pb, Zn, Au and Mo.

In the Black Hills of northeastern Wyoming, Au-Th-REE mineralization is found associated with alkalic igneous rocks. In addition to disseminated Au and Th-REE mineralization, some Pb-Zn-Ag replacement mineralization is known. The Rattlesnake Hills greenstone belt in central Wyoming was intruded by several Tertiary alkalic plugs that disrupted the Archean complex and provided some disseminated gold. Both moderate- and low-grade disseminated Au mineralization was discovered in this district during reconnaissance in 1982 by the author (Hausel, 1994).

Gold in breccias in a Tertiary alkalic complex in the Bear Lodge Mountains is also notable. This mineralization along with disseminated REE provides attractive exploration targets. In addition to gold associated with volcanism, Tertiary rocks included some widespread auriferous paleoplacers. Laramide uplifts provided large volumes of fluvial conglomerate and fanglomerate several of which contain considerable low-grade gold. Most notable are the Oregon Buttes-Dickie Springs, McGraw Flats and Miracle Mile paleoplacers, although others most likely will be discovered. Modern placers were mined for gold at a number of locations in Wyoming.

ARCHEAN GOLD DEPOSITS

The Archean geology of Wyoming is compared to South Africa, Western Australia and the Canadian Superior Province – all significant sources for greenstone gold mineralization. These areas include Archean cratonic rocks that for the most part have remained undisturbed for more than a billion years. The Wyoming craton, however, was modified by brittle deformation during the Laramide orogeny such that the current topography reveals blocks of ancient cratonic rock exposed in the core of several mountain ranges in a sea of younger Phanerozoic sedimentary rock and large portions of the craton lie hidden under Phanerozoic sedimentary rocks under the basins.

According to Condie (1976), the Wyoming craton may have been part of the Superior Province of Canada. Within and along the margin of the Wyoming craton are some notable precious metal deposits that include the Stillwater complex (Pt, Pd, Cr), Jardine (Au), Homestake (Au), South Pass (Au, Fe), Seminoe Mountains (Au, Fe), Rattesnake

Hills (Au), Lake Owen (Pd, Pt, V), Mullen Creek (Pd, Pt, V), Puzzler Hill (Pd, Pt, Ni, Au), Copper King (Au, Cu) and Ferris Haggarty (Cu, Au, Ag).

This Province is formed of a vast region of high-grade gneiss and migmatite intruded by granite and granodiorite with fragmented greenstone belts, eugeoclinal successions, layered mafic complexes, and high-grade supracrustal belts (Figure 1).

Granite-Greenstone Belts

Houston (1983) describes the low-grade metamorphosed supracrustal successions in the southern portion of the Wyoming craton to exhibit similarities to greenstone belts in other cratons. In the northern region of the Wyoming craton, the metamorphic rank of the supracrustal belts generally increases: these belts are lithologically distinct and consist of intercalated amphibolite and gneiss with subordinate metasedimentary rocks consisting of quartzite, metapelite, BIF (banded iron formation), amphibolite and minor metacarbonate. Exceptions include the Jardine belt of the Snowy Range block of the Beartooth Mountains in the northern portion of the craton, which was reported by Thurston (1986) to have similarities to the South Pass greenstone belt in the Wind River Mountains. It was Houston's contention that the greenstone belts represented the greatest potential for Archean mineralization in the Province.

In general, the Wyoming greenstone belts form tripartite successions of low-rank metamorphosed (upper greenschist to middle amphibolite facies) sedimentary, volcanic, and plutonic rock folded into a regional synclinorium. Bedding and most structural elements (i.e., foliation, isoclinal fold axes, auriferous shears) parallel the principal axis of the synclinorium. Although amphibolites-facies metamorphism predominates, the rank is relatively low resulting in preservation of primary textures. Pillow structures and porphyritic, amygdaloidal, spinifex and cumulate textures are preserved in some greenstone belts. Graded bedding, quartz pebbles, cross-bedding, and cut and fill channels occur in some metasedimentary rocks.

The lower portions of the greenstone belts are formed of ultramafic to mafic metavolcanic rock that includes hornblendic amphibolite, serpentinite, tremolite-talc-chlorite schist and metabasalt. These have compositions that suggest their precursors were high-magnesian tholeiitic basalts and tuffs, and komatiitic basalts and peridotites (Hausel, 1993).

These underlying successions are overlain by calc-alkalic metavolcanic rocks including meta-andesite, metadacite, felsic schist, as well as high-iron tholeiitic metabasalts (amphibolite, greenstone and metabasalt) and some metakomatiite (actinolite schist, hornblende-plagioclase amphibolite, tremolite-talc-chlorite schist, and minor serpentinite). Metasedimentary rocks include metagreywacke, BIF with lesser quartzite, graphitic schist, metaconglomerate and metapelite.

Greenstone belts in Wyoming include South Pass (Hausel, 1991), Rattlesnake Hills (Hausel, 1996) and Tin Cup in the Granite Mountains, the Seminoe Mountains (Hausel, 1994), Casper Mountain, Sellers Mountain, Esterbrook and Elmers Rock (Graff and others, 1982) in the Laramie Range, as well as smaller fragments in the Laramie, Medicine Bow, and Sierra Madre ranges (Condie, 1967; Houston, 1983). Of these, the South Pass, Seminoe Mountains and Rattlesnake regions have high potential for discovery of major gold deposits.

South Pass Greenstone (Gold) Belt

The South Pass granite-greenstone terrain represents a fragment of an Archean volcano-sedimentary belt exposed over 350 to 400 mi^2 near the southeastern edge of the Wind River Mountains. A large segment of the greenstone terrain projects under a blanket (<1 ft to > 2,000 ft) of Tertiary arkosic sandstone, siltstone and conglomerate, and at least two major gold deposits are interpreted to lie under this blanket (Love and others, 1978, Anweiler and others, 1980, Hausel, 1991, Foster Howland, personal communication). Based on geology and structure, this terrain is believed to host major undiscovered and undeveloped gold deposits in auriferous shear zones and veins, and in associated Tertiary paleoplacers and modern placers.

Successful exploration will need to focus on the following concepts: (1) all primary gold deposits are structurally controlled and unrelated to any particular rock type (i.e., ore shoots are structurally controlled with little to no evidence of lithologic control). (2) The total estimated gold content in paleoplacers is significant and suggests

hidden major lode gold deposits under the Tertiary sediments near the greenstone belt. (3) Exploration of the Tertiary paleoplacers should focus on black sand concentrates and magnetic anomalies in the paleoplacers. (4) Modern placers lie downstream from known lode. (5) Exploration of any modern placer (and paleoplacers) should focus on past flash flooding events since the gold is focused in pay-streaks between layers of unproductive gravel. (6) When dealing with lodes and placers in the district, one must visualize 3-dimensional models as nearly all exploration in the past has overlooked several ore deposits due to improper exploration models.

Geological evidence supports the existence of at least three major gold deposits in the district along with several smaller (but potentially productive) deposits. Major gold deposits are predicted to lie under Tertiary sedimentary cover near McGraw Flats and Dickie Springs. A third major gold deposit was identified at the Carissa mine near South Pass City. Detailed sampling and structural mapping between the Carissa and Miners Delight mines and in the Lewiston district will most likely lead to other significant gold deposits. A detailed sampling program would undoubtedly reveal several ore shoots, but even after the ore shoots were revealed, it will take proper interpretation of the shoots to find minable ore, as nearly all prospectors and geologists in past years have misinterpreted the complex geology related to known ore shoots.

Lode deposits. Shear zones in the greenstone belt have been described as narrow, foliation-parallel, cataclastic zones that exhibit brittle and ductile deformation and have strike lengths of dozens to more than 11,000 ft (Hausel and Hull, 1990). Widths are typically 2 to 15 feet, although greater widths occur at some mines, most notably the Carissa. For the most part, these structures are weakly mineralized along much of their trends with localized ore shoots that most likely follow the dip of cold closures. Shoots occur at pinches, swells, fold closures, attitude changes, and at intersections of structures: the most notable were recognized as steeply plunging fold closures, or classical saddle reef deposits (Hausel, 1991).

Historic reports indicate the tenor of shoots ranged from a trace to as much as 3,100 opt (ounces per ton) Au (Figure 2). Average mine grades varied from 2.06 ppm (0.06 opt) to 68.6 ppm (2.0 opt) Au with minor Ag (Hausel, 1989a). The continuation of these structures down dip has not been fully tested since the deepest gold mine (Carissa) is only 400 feet deep, and drilling has penetrated the mineralized structures to depths of only 930 feet below the surface (deQuadros, 1989). All other properties lack much if any subsurface exploration. This fact along provides evidence for incompetence in past exploration as nearly all lode deposits in the South Pass greenstone belt represent steeply plunging saddle reefs that continue to depths potentially of a few to several thousand feet.

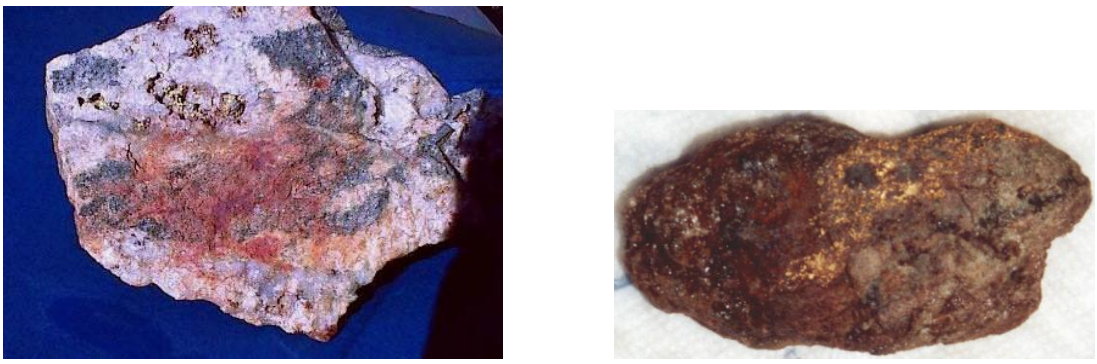
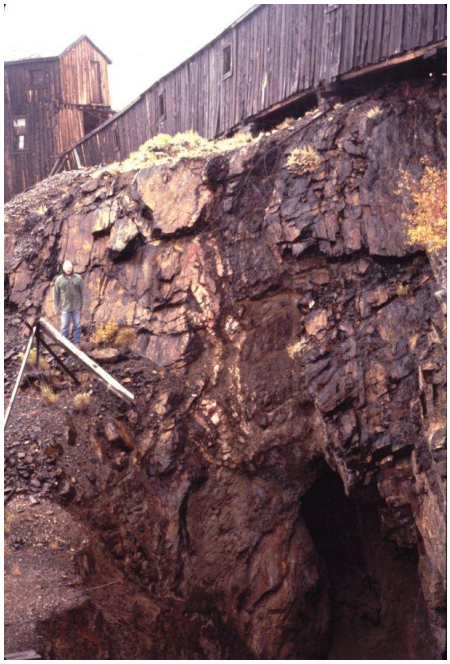


Figure 2. (a) Visible gold and wire gold in specimen from Carissa mine and (b) gossaniferous quartz from Carissa mine containing considerable visible gold.

Many auriferous shears and veins are localized in metagreywacke and hornblendic amphibolite with fewer in graphitic schist, meta-andesite, greenstone, greenschist, metatonalite, and actinolite schist. A large proportion of the shears are found along or adjacent to lithologic contacts of rocks of contrasting competency (Bayley, 1968; Hausel, 1987). The source of gold in shear zones was suggested by Bow (1986) to have been rocks of komatiite affinity. But recent stable isotope and fluid inclusion studies by Spry and McGowan (1989) are redolent of a greywacke source. Hausel (1991), however, was impressed by the ubiquitous occurrence of structurally controlled gold anomalies throughout the greenstone belt, essentially all independent of rock type and proposed that the gold was derived by metamorphic secretion during a 2.8 Ga regional metamorphic event, and the shears served as a permeable layer for gold mineralization that was focused in fold apexes along shear zones in subsequent deformation. Thus the entire

strike length of shear zones typically contain weakly to anomalous gold with periodic highly anomalous ore shoots in steeply plunging tight to isoclinal folds along the shear zones that continue down plunge several hundred to several thousand feet. Four deposits investigated by the author for this type of mineralization included the Carissa, Duncan, Lone Pine and Tabor Grand mines.

The *Carissa mine* is a major gold deposit with possibilities for a few to several million ounces of gold. The principal shear is 5 to 50 feet wide and enclosed by a broad rehealed fracture zone of weakly mineralized ore (Figure 3). Locally, the ore shoot is as much as 1000 feet wide and mostly unexplored. Beeler (1908) reported the ore averaged 10.29 ppm (0.3 opt) Au. Composite chip samples taken in the shear envelop yielded anomalous gold over a 300 ft width (Curran, 1926; Hausel, 1989a). Drill intercepts below the mine workings recovered core with 16 feet of ore that averaged 0.13 opt Au. Other drill holes intercepted 80 feet of mineralized rock that yielded 0.03 to 2.54 opt Au. The remainder of the shear envelope remains unexplored. Significant gold was intercepted in the mine workings, along strike beyond the mine workings and to depths of 970 feet (nearly 600 feet below the historic mine workings). Deeper tests along this structure would undoubtedly result in additional gold intersects. Based on the available sampling, the Carissa contains a mineralized zone that is a minimum of 970 feet deep, 300 feet wide with at least 750 feet of strike length. Potentially, this ore shoot is 1000 feet wide, several thousand feet deep and 1000 feet long! This major gold deposit was questionably withdrawn from mining and exploration by the State Legislature without any geological studies or research.



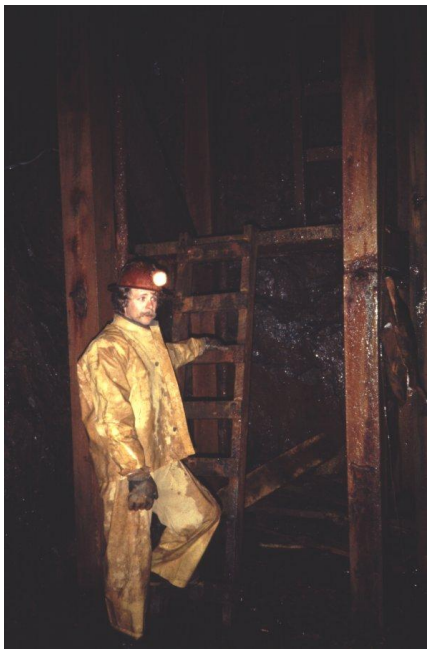


Figure 3. (a) Exposed shear zone at the Carissa mine (geologist for scale), and (b) Steve Gyorvary posses at 350 foot station in the Carissa workings prior to the mine being incorporated into the South Pass historic site.

At the *Duncan mine*, the foliation-parallel shear is folded and splayed producing a classical saddle reef ore shoot (Figure 4). The splay has an aggregate width of >40 feet adjacent to the shaft. Within the fold closure, gold values are greatly enhanced, and the nose of the steeply plunging drag fold averages ten times the amount of gold in the fold limbs.

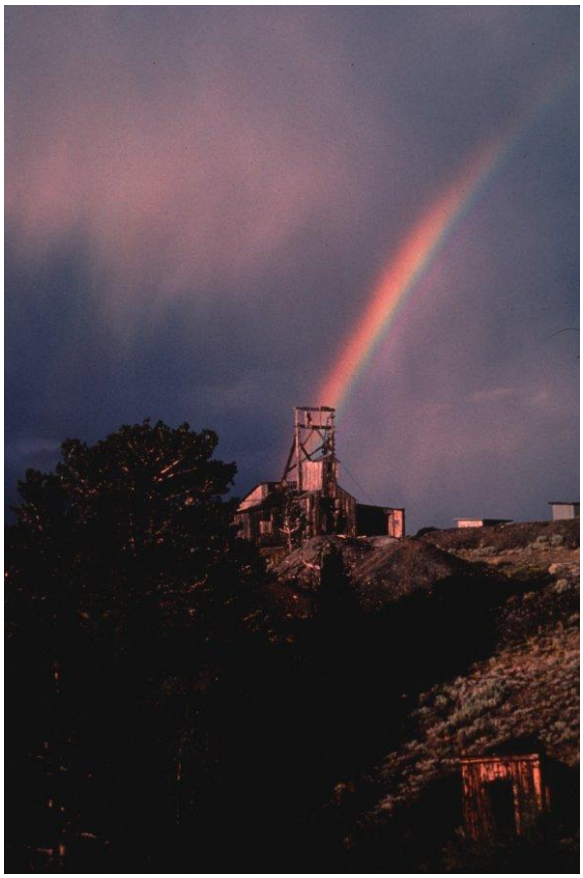


Figure 4. The Duncan mine is marked by a pot of gold at the end of a rainbow.

In the *Tabor Grand* mine, a 1 to 5 foot wide shear cuts hornblendic amphibolite. Samples of the shear yielded 0.06 to 58.0 ppm Au over a 350 foot length. While mapping the mine, a second shear was discovered parallel to the first nearly 20 feet south of the primary shear. Two samples taken in this shear yielded 1.7 and 7.0 ppm Au. Surface mapping extended the length of the shear another 800 feet to the east where an 8 foot channel sample assayed 3.8 ppm Au (Hausel, 1991).

The *Lone Pine* mine in the Lewiston district along the southeastern edge of the greenstone belt contains a hidden shear buried under a thin veneer of Tertiary South Pass Formation. The discovery trench exposed a 17 foot wide shear which yielded gold values of 0.47 to 3.5 ppm (Table 1). The maximum mineralized width and strike length of this structure have not been determined.

At the *Wolf mine* in the same district, representative samples yielded 23.3 ppm (0.68 opt) Au (Hausel, 1989a). This property was later examined by U.S. Borax, who determined it to be mineralized over a >100 ft width. The shear is traceable for a considerable strike length by using geomorphic features (topographic saddles).

Table 1. Chip channel and channel sample analyses in the South Pass greenstone belt (Hausel, 1989a).

SAMPLE DESCRIPTION	Au (ppm)	Ag (ppm)
Carissa Mine		
0 to 10 ft north of shear	0.4	--
10 to 20 ft north of shear	1.05	--
20 to 37 ft north of shear	2.5	--
0 to 10 ft south of shear	0.65	--
10 to 20 ft south of shear	0.25	--
20 to 30 ft south of shear	0.30	--
30 to 60 ft south of shear	0.35	--
30 ft composite north of shear	2.4	--
Duncan Mine		
0 to 2 ft west of fold closure in shear	3.0	2.2
2 ft channel across fold closure	33.0	6.0
0 to 5 ft east of closure	1.8	1.8
5 to 15 ft east of closure	6.6	2.7
15 to 25 ft east of closure	0.71	7.4
25 to 35 ft east of closure	0.53	1.0
Lone Pine Mine		
0 to 4 ft (E to W) in shear	0.47	2.5
4 to 7 ft (E to W) in shear	0.69	1.9
7 to 11 ft (E to W) in shear	3.5	4.3
11 to 17 ft (E to W) in shear	1.6	2.9

The South Pass greenstone belt has extensive iron deposits in the limbs of the South Pass synclinorium (see Hausel, 1991). The possibility of gold in the iron formation apparently was not considered during the 20 year operation of the Atlantic City iron mine. More than 90 million tons of iron ore were recovered, but it was not tested for gold. Samples collected a short distance southwest in the BIF by the author yielded anomalous gold (maximum of 1.3 ppm) as well as samples along the southeastern margin of the greenstone belt.

Hidden gold deposits. There is little doubt that hidden gold deposits underlie Tertiary cover along the northern and southern margins of the greenstone belt. Both of these deposits are probably major deposits particularly since they have released millions of ounces of gold during past erosional episodes. The US Geological Survey traced the McGraw Flats paleoplacers to a source area near Roundtop Mountain immediately east of the Atlantic City Iron Ore mine (Antweiler and others, 1980). The resulting paleoplacers and placers downslope from this source area were estimated to potentially host 4 to 5 million ounces of gold. The probably source area is overlain by Tertiary sediments that most likely cover significant gold mineralization.

At Dickie Springs, enormous paleoplacers were estimated by the US Geological Survey to host as much as 28.5 million ounces of gold (Love and others, 1978) (figure 5). The source of the gold was unknown. However, exploration by Hecla Mining Company in the 1980s resulted in the discovery of distinct linear magnetic anomaly marking the edge of the South Pass greenstone belt beneath the present site of the Continental Fault scarp. The anomaly was accompanied by IP anomalies that suggest potential sulfide facies BIF at depth. Some gold-bearing sulfide facies iron formation cobbles were found in this area in the paleoplacers during exploration (Foster Howland, personal communication, 1989).

In addition to the paleoplacers gold, considerable gold has been recovered from modern placers in the South Pass Greenstone belt (Figure 6).

Figure 5. Gold recovered from Dickie Springs near Oregon Buttes. Photo from J. David Love.

Figure 6. (a) A 7.5 ounce nugget recovered by a modern prospector along Big Atlantic Gulch near the center of South Pass. (b) considerable gold recovered from the Rock Creek placer by Gerald Stout. (c) A 34 ounce nugget found along Rock Creek in the early 1900s

Seminoe Mountains Greenstone Belt

The Seminoe Mountains granite-greenstone belt near Sinclair Wyoming in southern Wyoming provides targets for high-grade gold mineralization in quartz-carbonate veins and potential for large-tonnage, low-grade disseminated gold in epigenetically altered zones in mafic amphibolites and banded iron formation, and in gold paleoplacers. The district only has limited potential for modern gold placers, and has potential for a major diamond deposit(s). In past years, exploration focused on narrow quartz veins and minor copper deposits, and the possibility for large-tonnage, disseminated gold deposits in altered rock has been completely overlooked, even though these may represent the better gold targets. One of the principal altered zones lies in the vicinity of the Penn mines and was first recognized by Klein (1981).

Initial gold discoveries at Bradley Peak were on well-defined, gold-quartz veins. Ore was reported to assay 5 opt Au with periodic assays as high as 12 opt (Morrow, 1871). In 1878, a congressional report summarized ... "*A visit to the Seminoe Mountains found the mining camp for the most part deserted. A sample collected from the Ernst tunnel at this time assayed $106.20 in gold per ton* (5.14 opt)" (Reed, 1878).

In addition to gold, Harrer (1966) estimated that about 100 million tons of BIF occurred at Bradley Peak at the west end of the Seminoe Mountains. In 1981, several quartz vein samples with visible gold were found by the author in this area. One sample of quartz yielded 2.87 opt and the more highly mineralized samples were not assayed. One sample of BIF yielded >1.0 opt Au (Hausel, 1989).

The core of the Seminoe Mountains consists of Archean metasedimentary and metavolcanic rock exposed in a broad, vertically plunging, fold. The rocks are lower amphibolite grade and were intruded and folded by syntectonic granodiorite >2.6 Ga ago (Snyder and others, 1989). The Seminoe Mountains were uplifted during the Laramide orogeny and are bounded on the southwest by a low angle reverse fault and on the north by the Kortes Fault. The Seminoe Mountains have similar rock types as South Pass, but in different proportions. For instance, the relative volume of metagreywacke in the Seminoe Mountains is less than South Pass, BIF is abundant, and the belt includes a thick section of aphyric and spinifex-textured basaltic komatiite and cumulate-textured serpentinite and metaperidotite (Klein, 1981; Snyder and others, 1989).

Gold is concentrated in a 0.5 mile diameter zone of altered metagabbro and metabasalt near the western margin of the belt (Klein, 1981; Hausel, 1989b). Samples of quartz, BIF, and altered metatholeiite from this region are anomalous in gold. Amphibolites in the altered zone have been overprinted by chlorite, carbonate, quartz, and sulfide alteration assemblages (Klein, 1981). The zone is transected by narrow quartz-calcite veins and stockworks containing minor pyrite and chalcopyrite. Ore shoots often yield visible gold and exhibit control by folding.

A sample from an 8-foot-wide section of iron formation yielded 33.5% Fe, 0.5 opt Ag and 0.02 opt Au (Dickman, 1906). Reports of precious metals in the BIF were common. Lovering (1929) wrote, *"High gold assays are said to have been obtained from the banded jasper of the iron formation, but the writer was unable to verify this statement, as the samples of the iron formation that he gathered carried only traces of gold, with one exception, which ran 0.01 ounce in gold to the ton."*

In 1981, the author collected select samples of quartz and BIF in the Penn mines area at Bradley Peak. BIF samples were selected because of physical evidence of epigenetic alteration (crosscutting carbonate veins with pyrite). One was highly anomalous and yielded 1.36 opt Au. In every sample but one, clear evidence of epigenesis was present. Another sample yielded anomalous zinc (0.28% Zn), supporting an epigenetic origin for gold. One BIF sample was found at the Penn Mines that contained visible gold (John Wells, personal communication, 1984).

Vein samples in the vicinity of Bradley Peak generally yield anomalous gold. These are narrow (<3 feet wide), sulfide-bearing (pyrite and chalcopyrite), quartz-carbonate veins in propyllitically-altered amphibolites (metabasalt and metagabbro). The propyllitically-altered zone is confined to the eastern half of section 6, T25N, R85W. The amphibolites are moderately to pervasively altered to chlorite, carbonate, actinolite and epidote. Samples from the altered zone range from <0.05 ppm to 89.3 ppm (2.6 oz/ton) Au, <1.0 to 55.0 ppm (1.6 oz/ton) Ag, 0.03 to 3.75% Cu, 3.0 ppm to 0.39% Pb, and 22 ppm to 4.3% Zn.

At a few locations, wallrocks were found that exhibit distinct limonitic alteration and/or are cut by quartz-carbonate veinlets and were sampled. Limonite-stained metatholeiite with secondary quartz is often anomalous in precious metal. One sample collected by the author yielded 9.8 ppm Au, 12.0 ppm Ag, and 0.81 % Cu. Another sample of chloritized metatholeiite yielded 0.12 ppm Au, <1.0 ppm Ag, and 0.09% Cu. A widespread sampling program of this area is needed.

Quartz veins exhibit three orientations on Bradley Peak (N70°E, N50°W & N-S). Isoclinally folded quartz was sampled at two locations along Bradley Peak. These yielded anomalous precious metals (4.6 ppm & 6.8 ppm Au, 5.2 ppm & 4.2 ppm Ag) and suggest enrichment in fold closures. Vein-vein and vein-shear intersections could not be assessed during this study because of lack of exposure.

The Deserted Treasure #1 adit on Bradley Peak was driven across foliation to intersect a N70°E trending, 46°N dipping vein cropping out on the surface for 300 to 400 feet. A sample of sulfide-bearing boxwork quartz from the mine dump assayed 1.2 ppm Au and 3.6 ppm Ag and several samples of quartz contained visible gold.

The nearby Deserted Treasure #2 adit was driven across foliation to intersect the same vein. Select samples from the mine dump were highly anomalous and yielded 0.87 ppm to 89.3 ppm Au, <2.0 to 18.0 ppm Ag, and 0.06 to 0.39% Cu. In 1981, samples with visible gold were also collected from this dump (Hausel, 1994). At the King mine located downslope from the Deserted Treasure adits, a select sample yielded 6.8 ppm Au and 4.2 ppm Ag (Hausel, 1994).

The Sunday Morning prospect was developed on a copper-stained shear in metavolcanics. A channel cut across the shear yielded 1.8% Cu, 45.4 ppm Ag, and 0.07 ppm Au. A grab sample of cupriferous quartz from the dump assayed 5.8% Cu, 26.9 ppm Ag, 2.1 ppm Au and 0.2% Pb. This shear (the Apex shear) is traceable along a northeasterly trend for 2 miles and is marked by well-developed penetrative foliation. Copper mineralization is confined to small, localized pods, in the shear zone. Both chrysocolla and cuprite are common. Bishop (1964) reported some visible gold.

At the Apex adit, a short distance west from the Sunday Morning prospect, the shear grades into a quartz breccia vein with angular clasts of country rock and more than one generation of quartz. Visible gold was collected near the portal (Charlie Kortes, personal communication, 1989). Samples assayed 0.1 to 3.81% Cu, 0.3 to 63.8 ppm Ag, 0.001 to 0.013 ppm Au, 61 ppm to 0.95% Pb and 68 ppm to 0.23% Zn.

Gold Placers. Modern placers are not significant as all streams in the district are immature, intermittent and not conducive to significant placer development. Even so, some placer gold exists in Deweese Creek as it drains the Penn Mines at Bradley Peak. A large, unexplored, gold and probable diamond paleoplacer occurs along the northern flank of the range. This Tertiary paleoplacer consists of unconsolidated conglomerate with BIF pebbles, cobbles and some boulders. Where sampled, colors and flakes of native gold were panned as well as kimberlitic indicator minerals.

On the east side of the North Platte River, the author recovered visible gold, four grains of chromian diopside and eight rounded yellow-orange to purple pyrope garnet. The pyropes had characteristic color and scheen of sub-calcic, high chrome, magnesian pyrope typical of diamond-stability indicators. West of the North Platte River, a second

sample collected more than a mile from the first, yielded gold with pyrope garnets. Some of the garnets were tested on the University of Wyoming microprobe and all yielded sub-calcic, high chrome magnesian chemistry similar to G10 diamond stability pyropes. The presence of these garnets suggests the presence of an undiscovered highly diamondiferous pipe that shed debris into the paleoplacer. The presence of chromian diopside in the sample east of the North Platte River supports a nearby diamond source and one distinct depression was found upstream from this location. The roughly elliptical to circular depression is located in granite. At another location, at the junction of Little Long Creek and Long Creek a few miles to the west, several flakes of visible gold were recovered from the paleoplacer indicating that this is a widespread, previously unreported gold deposit (Charlie Kortes, personal communication, 1990).

Rattlesnake Hills greenstone belt

The Rattlesnake Hills supracrustal belt is located in the Granite Mountains. Within this belt, a 500 ft long, mineralized vein (metachert), was found in 1981, and named the Lost Muffler prospect. Composite chip samples 3.6 ft in length were taken in the vein, and assayed 7.5 and 4.5 ppm Au (Hausel, 1989a). Later exploration in this area intersected auriferous BIF and gold-bearing Tertiary alkalic igneous rock. Drill intercepts included 10 ft of 10.3 ppm Au in BIF and 250 ft of 2.1 ppm in the Tertiary volcanics.

The Rattlesnake Hills (RSH) in central Wyoming form an Archean age greenstone belt intruded by 42 alkalic intrusives. Several types of gold mineralization have been recognized in the district (Hausel, 1996).

(1) Exhalative gold (moderate to low-grade) in cherts and silicified zones parallel to foliation.
(2) Stockwork gold in basement gneisses
(3) Secondary gold in veinlets crosscutting banded iron formation
(4) Disseminated gold in Tertiary breccias.

The possibility of gold in (1) localized skarns along the northern flank of the exposed RSH and also in (2) gossaniferous Tertiary alkalic intrusives have not yet been investigated.
Gold in the RSH was initially recognized by Hausel (1996). Since the discovery, several companies have entered the area beginning with American Copper & Nickel Company a short time following the initial discovery. ACNC focused on gold-bearing exhalites. Later, Canyon Resources initiated exploration in the district for disseminated gold, which was followed by Newmont Gold Company. Newmont identified a gold resource of about 250,000 ounces of low-grade gold based on drilling. However, this was based on RC holes that showed gold values of about $1/5^{th}$ that of a single core hole. Potentially, the gold was being lost in RC drilling and possibly a >1 million once gold deposit was identified. Currently, Bald Mountain mining is exploring this region.

RSH consists of refolded Archean metamorphic rocks intruded by several Tertiary (42 Ma) alkalic plugs and dikes (Pekarek, 1977). The Precambrian rocks have been subjected to several episodes of deformation. According to Hausel (1996), three episodes of folding are recorded in the Precambrian rocks, and at least two later episodes of brittle deformation disrupted the greenstone terrain during the Phanerozoic.

The RSH is dominated by a thick metagreywacke succession, which encloses 2,000 to 5,000 feet of metatholeiitic volcanics with minor metasediments that include metagabbro, metabasalt, uncommon graphitic schist and metachert. The metagreywackes are underlain by 2,500 feet of metavolcanics dominated by well-preserved pillow metabasalts and amphibolites with minor intercalated ultramafics and intermediate metavolcanic schists.

In the vicinity of three Tertiary alkalic plugs - Goat Mountain, Sandy Mountain, and Oshihan Hill in sections 23, 24, and 25, T32N, R88W, the metatholeiites and metagreywackes have been brecciated and are locally gossaniferous.
The supracrustals lie in contact with gneiss along the southwestern flank of the belt, which has been fractured and rehealed producing a stockwork-like network of veinlets. A sample of the iron-stained gneiss (Hausel, 1996).

Other Supracrustal Belts

The Wyoming Province encloses medium to high-rank metamorphosed supracrustal belts. These belts occur in the Tobacco Root Mountains, the Ruby and Gravelly Ranges of Montana, and the Copper Mountain district of the Owl Creek Mountains, Wyoming. In Wyoming, the Hartville uplift in the southeastern corner of the Province consists of relatively low-rank metamorphosed eugeoclinal sedimentary and volcanic rocks with numerous gold anomalies.

Copper Mountain. The Copper Mountain district in the eastern Owl Creek Mountains is interpreted as a high-grade supracrustal belt (Hausel and others, 1985). It is intensely metamorphosed and isoclinally folded such that all primary textures have been essentially destroyed or overprinted by foliation. Two mappable units in the belt are similar in appearance and consist of intercalated amphibolite and quartzofeldspathic gneiss. A third unit is formed of gneiss, amphibolite, BIF, metapelite, and quartzite.

Scattered mineral deposits in the Copper Mountain district include stratiform scheelite, vein Cu and Au, and REE-Ta pegmatites. One relatively significant development (the DePass mine) lies along the eastern edge of the district in a 50 ft wide Proterozoic mafic dike emplaced in Archean granite. This mine was driven into the dike and produced a minimum of 568,000 lbs of mill concentrates in the early 1900s with receipts for Cu, Au, and Ag. The mine has more than 11,000 ft of workings (Hausel and others, 1981). Other than the DePass mine, this belt appears to have little potential for gold mineralization.

Hartville uplift. The Hartville uplift in southeastern Wyoming has yielded more than 5 million lbs of copper and 45 million tons of iron from Archean schists and overlying Phanerozoic rocks. Mineral deposits in the region of interest for gold include the McCann Pass pyritiferous massive sulfide deposit, and scattered Cu-Ag-Au-U unconformity deposits. The Silver Cliff mine in the northern portion of the uplift was initially developed for gold and silver in the 1870s and later mined for uranium in the early and mid 1900s (Hausel, 1989a). Mineralization at the Silver Cliff is localized in fault gouge and along a Precambrian-Cambrian unconformity.

The Hartville uplift is principally known for its massive hematite. Hematite was mined for many decades from hematite schist until 1981. Total recorded production amounted to more than 45 million tons of ore with some by-product copper. These deposits often contain copper as well as anomalous gold. For instance, the Michigan mine in the central portion of the uplift encloses two hematite pods. The northern ore body contains 75 million tons of 25% Fe, and the southern deposit contains 41 million tons of 24% Fe (Wilson, undated). The upper portion of these deposits are copper stained and have anomalous gold (Woodfill, 1987).

Unconformity deposits in the northern Hartville uplift are found at the Silver Cliff shaft. This shaft was developed on a Precambrian-Phanerozoic unconformity and mineralized reverse fault. Assay reports indicate the ore contained none to 10.88 % Cu, none to 15.04 opt Ag, 0.001 to 3.39% U_3O_8 with anomalous gold (Wilmarth and Johnson, 1954). In the southern portion of the uplift, Kerr McGee explored a copper-stained Precambrian-Paleozoic unconformity recovering samples with cerargyrite, unmangite, electrum, and native gold (Kerr McGee Corp., 1988).

South of the Silver Cliff mine, a contact between hanging wall dolomite and footwall schist is mineralized over a 1 to 15 ft thickness. Lenses from the Copper Belt Group assayed 2 to 8 % Cu and the adjacent altered iron-stained schist contained 0.05 to 0.58 opt Au and 2 to 5 opt Ag (Ball, 1907).

In the southern portion of the uplift, an extensive gossan at "Gossan Hill" along the McCann Pass fault was prospected in the 1970s. Outcrop and shallow drill holes recovered samples with elevated Cu, As, and Zn. Deeper drilling intersected thick zones of anomalous mineralization including 10 ft of 0.8% Zn, and 2 ft of 1.2 % Zn and 0.08 opt Au (Woodfill, 1987).

PROTEROZOIC MINERALIZATION

Most Proterozoic rocks in Wyoming are restricted to the southeastern corner of the state in the Laramie, Medicine Bow, and Sierra Madre Mountains. Precious and base metals south of the Cheyenne Belt shear zone occur in quartz veins, massive sulfides, a porphyry, and in layered mafic intrusions. In the Keystone district of the Medicine Bow Mountains, N60°W-trending shears are loci for narrow veins. These are gold- and copper-bearing, pyritic, quartz-carbonate veins in tensional faults subsidiary to the Mullen Creek-Nash Fork shear zone (Currey, 1965). Mineralization was accompanied by silicification in the form of small, irregular quartz veinlets and the wallrock is enriched in epidote.

Gold was found in quartz and in pyrite and pyrrhotite masses in mylonite selvages adjacent to the vein. The vein lies in sheared diabase that intrudes quartz-biotite gneiss country rock. The shear is 2 to 6 ft wide, locally splays to 300 ft and continues 4,500 ft to the southeast to the Florence mine. Available information indicates the Keystone ore averaged 41 ppm Au. When the Keystone mine ceased operations in 1893, 100,000 tons of reserves were reported

in site. Eight samples collected from the mine dump by Loucks (1976) yielded 6.5 ppm to 300 ppm (0.19 to 8.75 opt) Au and averaged 117 ppm (3.41 opt) Au. At the southeastern end of the Keystone trend, the Florence mine was developed in quartz diorite. The ore occurred as 'kidneys' of auriferous pyrite which assayed from 257 ppm to 1,656 ppm (7.5 to 48 opt) Au (Currey, 1965). Samples collected from the mine dump by Loucks (1976) yielded values ranging from 2.06 ppm to 799 ppm (0.06 to 23.3 opt) Au.

Volcanogenic massive sulfide deposits occur in the Green Mountain Formation (Proterozoic) of the southern Sierra Madre. However, these are zinc and copper dominate and contain very little gold. But at least one deposit in this terrain in the Laramie Range has been classified as a Au-Cu porphyry. The Copper King mine in the Silver Crown district west of Cheyenne (Klein, 1974), was developed in weakly foliated and hydrothermally altered quartz monzonite and granodiorite. A shaft sunk in a potassium-silicate altered zone is surrounded by propylitically altered rock (Hausel, 1997).

The Copper King was initially drilled by the U.S. Bureau of Mines in the 1950s, later by Asarco, and more recently by Caledonia Resources, Ltd., Royal Gold and others. Drilling outlined a 35 million ton open pitable ore body averaging 0.755 ppm Au and 0.21 % Cu (Nevin, 1973). Caledonia Resources outlined a higher grade zone consisting of 4.5 million tons averaging 1.5 ppm Au that was open in several directions. The Copper King porphyry is mineralized along a 600 to 700 ft strike length, and a 300 ft width that is open at depth (Stockwatch, 1987). Currently, the resources suggest a million ounce equivalent deposit of gold with some copper.

Two large layered mafic complexes (1.8 Ga) may have been part of a larger layered complex (Figure 7). This deposit in the Medicine Bow Mountains has considerable potential for palladium, platinum and vanadium. The 60 mi^2 Mullen Creek mafic complex abuts against, and is sheared by, the Mullen Creek-Nash Fork shear zone. This complex is highly deformed and metamorphosed. Along the northeastern corner of the complex was the historic New Rambler mine. The New Rambler shaft was collared in sheared and hydrothermally altered mafic rock and sporadically operated from 1900 to 1918 producing 6,100 tons of copper ore with values in Au, Ag, Pt, and Pd (Hausel, 1989a). The source of the platinoids was suggested by McCallum and Orback (1968) to be hydrothermally remobilized from a platinum reef hidden at depth. Six miles east of the Mullen Creek mafic complex is a second layered intrusive (Lake Owen complex). This intrusive is of similar size, but is essentially unmetamorphosed. Exploration activities in the past few years have isolated some significant Pt, Au, and Pd anomalies in the complex.

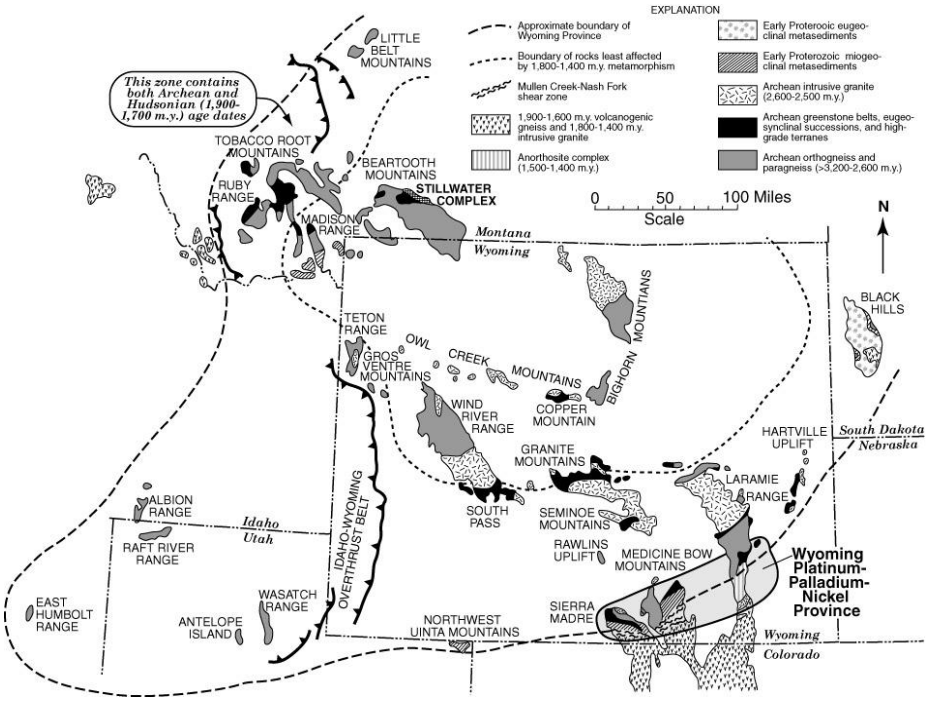


Figure 7. Location map of the Wyoming Platinum-Palladium-Nickel province which encloses the Mullen Creek, Lake Owen and Puzzler Hill deposits.

North of the shear, precious metals are found in narrow veins and in thick quartzites with some copper. Gold was detected in quartz pebble conglomerate and in shear zones in this area. Vein deposits in the Gold Hill district occur as narrow, rich, quartz veins with common visible gold. Specimen samples testify to the richness of the veins. Historic reports claim some specimen grade material from the Acme mine at Gold Hill assayed 2,100 opt Au. Unfortunately, these veins are narrow (0.5-2 ft wide) and spotty. One shear examined by the author in the Lewis Lake area of the Medicine Bow

Mountains is >100 ft wide and traceable for 2,000 ft. The shear occurs in limonitic quartz-mica schist. Samples of pyritized schist from the shear yielded 4.1 ppm (0.12 opt) Au (Dersch, 1990).

Mineralized quartzites occur at several localities in the Sierra Madre. Gossans in quartzites were prospected in the late 1800s and led to the development of some important copper mines. Two prominent mines were the Ferris-Haggerty and the Doane-Rambler. The Ferris-Haggerty is interpreted as a remobilized stratabound deposit (Hausel, 1986). During its operation (1902 to 1908) the Ferris-Haggerty was an internationally prominent mine. The massive chalcocite minor chalcopyrite ore was found filling irregular quartzite breccias along the contact between hanging wall schist and the underlying quartzite (Spencer, 1904) of the Magnolia Formation. Ore shoots greater than 20 ft thick were high-graded for the rich (30-40 % Cu) ore, and much of the lower grade material was left as waste. These shoots averaged 6 to 8 % Cu and carried some Au and Ag (Beeler, 1905; Spencer, 1904). Beeler (1905) reported the ore contained 3.4 to 15 ppm (0.1-0.44 opt) Au. The mine was mapped during World War II, and according to Ralph E. Platt (pers. comm., 1988), the steeply dipping quartzite flattens out in the lower mine workings and large blocks of "low grade" ore (6-8% Cu) remain in place. The property was explored for stratiform Cu-Au-Ag mineralization by Exxon Minerals in the early to mid 1980s and significant gold anomalies were discovered. More recently, the ore zone was examined by the author. The ore has the appearance of a copper-bearing Protorozoic metaconglomerate.

Proterozoic age quartz pebble conglomerate occurs in the thick miogeoclinal wedge in the northern Medicine Bow Mountains and Sierra Madre. These conglomerates were of considerable interest in the late 1970s after they were discovered to be radioactive (Houston and Karlstrom, 1979). During the mapping of these conglomerates some samples were tested for precious metal content. Gold values as high as 10 ppm were detected from a conglomerate near Dexter Peak in the Sierra Madre. Even though similarities to the Witwatersrand conglomerates have been noted (e.g. Karlstrom and others, 1981), these rocks still have received only minor attention for gold. Exxon explored and drilled some of the conglomerates in the late 1970s in search of U and Th.

PHANEROZOIC MINERALIZATION

Gold anomalies are scattered throughout the Phanerozoic record, although most are weak with the exception of gold associated with some Tertiary volcanics, paleoplacers and some modern placers. The Cenozoic of Wyoming includes poorly studied and unexplored gold and silver deposits and anomalies. Only a few are discussed and the reader is referred to Hausel (1989a) for a treatise on these.

In northwestern Wyoming, paleoplacers and associated reworked modern placers cover an extensive region. These quartzitic conglomerates and sandstones range in age from Late Cretaceous to Miocene and include associated Quaternary placers. The average gold content is anomalous, and the gold is very fine (Table 3) (Antweiler and Love, 1967). Most past prospecting activities have been confined to reworked alluvial and bench placers primarily along the Hoback and Snake Rivers.

Stratigraphic unit	Average Au (ppb)	Maximum assay (ppb)
Quaternary alluvium	103	2,000
Miocene (?) conglomerate	65	290
Pass Peak Fm(Eocene)	47	250
Wind River Fm(Eocene)	222	2,000
Early? Eocene conglomerate	94	400
Pinyon Conglomerate (Paleocene)	86	6,000
Ft Union Fm (Paleocene)	35	300
Harebell Fm (Late Cretaceous)	65	1,000

Table 3. Reported gold content of conglomerates in northwestern Wyoming (Antweiler and Love, 1967).

At the Twin Creek paleoplacer on the northeastern margin of the South Pass greenstone belt, more than one billion cubic yards of gold-bearing gravel were described by Antweiler and others (1980). The Oregon Buttes paleoplacer along the southern margin of the South Pass greenstone belt is estimated to contain more than 28.5 million ounces of

gold (Love and others, 1978). Other significant paleoplacers occur in and along the margins of the greenstone belt, but for the most part remain unexplored.

In 1910, gold was discovered along the Wind River, Little Wind River, and Popo Agie River in the basin. The precious metal was found in terrace gravels capping benches and buttes and in the nearby plains, mesas, and uplands for thousands of feet to a few miles from the present drainages. The deposits were reported to average 12 to 14 feet thick over widths of 3 to 4 miles. The gold is very fine tablet-like particles smaller than a pinhead. In 1913, gravels were tested and varied from none to 0.016 oz/yd^3 and averaged less than 0.0025 oz/ yd^3 Au. Two dredges operated in the Wind River. The Neble Dredge operated in a pay zone that ranged from 0.007 to 0.016 oz/ yd^3 and averaged 0.014 oz/ yd^3. The gold-bearing gravels averaged about 22 feet thick. The Clark Dredge, a few miles west of the Neble Dredge, treated gravels averaged 0.038 oz/ yd^3 (Schrader, 1913). The demise of the district was the gold was too fine to be recovered efficiently.

In the Black Hills, mineralization is reported in the Tertiary alkalic complexes of the Bear Lodge Mountains, Mineral Hill district, and Black Buttes. In the Bear Lodge Mountains, gold has been reported in fluorite veins, pegmatites, and in feldspathic breccia. A potential for large auriferous breccias in alkalic host rocks in this area is considered very high. One elongate intrusive breccia (120 by 2,000 ft) contained disseminated gold ranging from 0.34 to 1.7 ppm. The deposit averages 0.72 ppm (International Curator Resources Ltd, 1988 Ann. Rept.). This region also includes one of the largest, low-grade rare earth and thorium deposits in the United States (Staatz, 1983).

The Mineral Hill district to the east has a history of placer gold and tin production. The author identified two horizontal pyritiferous quartz veins at the Treadwell open cut that yielded maximum gold values of 130 ppm (3.79 opt) and silver values as high as 330 ppm (9.62 opt) (Hausel, 1997). Previous work in the district by Welch (1974) identified several gold anomalies including a jasperoid that assayed 5 ppm Au and 7 ppm Ag. Black Buttes lies 8 miles west of Mineral Hill and is formed of Tertiary phonolites and trachytes intruded into Paleozoic limestone. Contact replacement mineralization (Zn, Pb, Ag, Mo, F) occurs in the Pahasapa Limestone (Mississippian), but the surface exposures are limited (Hausel, 1989a).

The Absaroka Mountains in northwestern Wyoming include several Cu-Ag porphyry complexes, several of which are located within wilderness. These two porphyries contain anomalous Cu, Mo, Pb, Zn, Ag, Au, and Ti, and include disseminated, stockwork, and vein mineralization (Hausel, 1982). Published reports indicate the porphyry hosts a minimum of 1.23 billion lbs of Cu, 13,500 lbs of Mo, 121,000 oz of Au, and 5.6 million ounces of Ag (Paydirt, 1985). The contained metals are worth a minimum of $1.5 billion at 1989 prices. Some vein samples collected at the back of some silver mines in the district averaged >100 opt Ag over the width of the veins and shear zones.

Throughout Wyoming, many enigmatic gold anomalies have been reported. These include gold associated with coal in the Black Hills, gold anomalies in uranium roll fronts (Gordon Marlatt, pers. comm., 1989). Marlatt investigated a 200 mi^2 anomaly in the Green River Basin in the vicinity of Farson (south of South Pass) and recovered one sample with visible gold. The gold occurred as a irregular-shaped microscopic sliver. Many of these anomalies are possibly due to detrital gold eroded from nearby gold districts. But others are not easily explained by detrital transportation but instead may represent geochemically transported gold leached from Tertiary ash falls (Gordon Marlatt, pers. comm., 1988). Other gold anomalies were detected in a number of locations along the northern edge of the Medicine Bow Mountains near Arlington (Hausel and others, 1994). Most remain unexplored.

Most commercial modern placers in the State were mined for gold, although the Douglas Creek placers in southeastern Wyoming also possess platinum and palladium and potentially diamonds, the Clarks Camp placers in the northern Wind River Range contain anomalous monazite in addition to gold, and the Mineral Hill placers in northeastern Wyoming also have tin, tantalite, and magnetite. Monazite placers also occur in the Shirley Basin in southeastern Wyoming (J.D. Love, pers. comm., 1990). Statistics on gold nuggets are incomplete, although walnut-size nuggets have been recovered from the Mineral Hill district, the Douglas Creek district, and the South Pass greenstone belt. The largest nugget found in Wyoming may have been a 34 ounce nugget from Rock Creek in the South Pass greenstone belt. History also records a boulder with nearly 40 pounds of gold was found in the same area prior to 1905 (Hausel, 1989a). This region also has several potentially rich, but unexplored placers (Hausel, 1991). Many other placers have also yielded significant gold including the Douglas Creek district in the Medicine Bow Mountains and some placers in the Sierra Madre (figure 8).

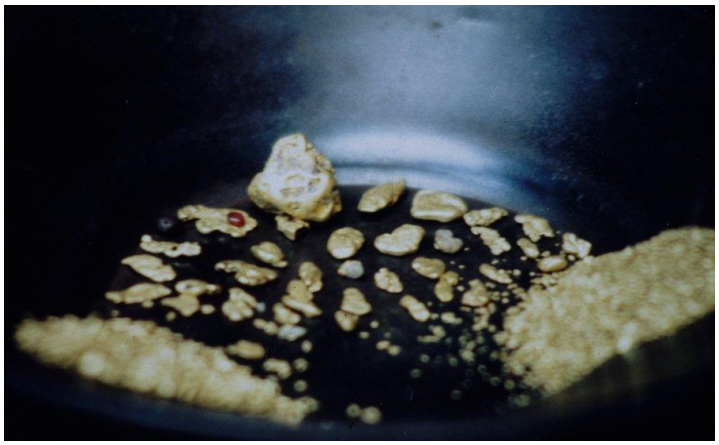


Figure 8. Placer gold from Douglas Creek near the Keystone mine.

SUMMARY

Significant gold mineralization in Wyoming has been identified in Archean greenstone belts, Tertiary alkalics, and in Tertiary paleoplacers. The geology of the state suggests that some major gold deposits remain undiscovered and unexplored in some of these regions. The author anticipates that continued rise in gold prices will lead to significant gold discoveries in several of these areas including South Pass, Seminoe Mountains, Rattlesnake Hills, Bear Lodge and Mineral Hill in particular.

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